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Reverse airflow drying of steamed paddy and its effect on the rice quality and energy consumption

Hasannia, F. [1], Tajaddodi Talab, K. [2]*, Shahidi, S. A. [3], Ghorbani-Hasansaraei, A. [4]

1. Ph.D student of Department of Food Science and Technology, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran.
2. Assistant professor, Rice Research Institute of Iran, Agricultural Research, Education and Extension Organization (AREEO), Rasht, Iran.
3. Associated professor, Department of Food Science and Technology, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran.
4. Associated professor,Department of Food Science and Technology, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran.

ABSTRACT

Non-uniform drying and head rice reduction due to non-movement of paddy in common fixed bed dryers is one of the basic problems in rice milling factories. In order to investigate and provide a suitable drying method with the approach of creating uniformity in drying process, reducing losses, and saving energy consumption, a two factorial experiment in completely randomized design (CRD) was used. The factors were the initial moisture content (IMF) of paddy at two levels (16 and 18%) and drying methodat 4 levels (one-way air flow, reverse air flow in 1 hour, 2 hours and 3 hours and then continuation of drying process the same as one-way airflow). The same drying air temperature and air velocity was considered for all treatments. In both moisture treatments, three hours reverse air flow drying has the highest head rice (75.7-75.86%) and the lowest energy consumption (41-49 MJ/kg water). The highest energy consumption with the amount of 79 and 67 MJ/kg water was belonging tothe one-way air flow treatment of paddy with high and low IMC (respectively).In one way airflow, dried paddy in 10 cm from the bottom layers of dryer has the lowest amount of head rice (63.65%). In both moisture treatments, the results of mixed layers showed that one hour reverse air flow drying with values of 68.28-68.68% had the lowest head rice. Also, drying method had no significant effect (P>0.05) on the cooking quality.

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*Corresponding Author E-Mail:
dr2eng@yahoo.com

1. Introduction

Freshly harvested paddy from the field must be dried in time for storage and conversion operations [1]. The delay in the drying operation and its inefficiency can reduce the grain quality and increase the waste [2]. Rice is a heat-sensitive biological material, and some of its quality properties, such as the amount of healthy rice and the color of white rice produced, are significantly affected by drying conditions [3-4]. Rice drying is a unit operation that consumes a lot of energy [5-6]. High energy consumption in the process of drying rice, one of the main problems of producing countries It is considered as a rice producer [7]. The energy cost in the drying process accounts for almost two-thirds of the total cost of the post-harvest processes of paddy [8]. Therefore, any change in the drying method that reduces costs is of interest to processing industries [9]. In general, rice mills in the rice-growing regions of the country, especially Gilan and Mazandaran provinces, use fixed-bed box dryers to dry paddy. The main weakness of these dryers is the lack of uniformity of the drying operation [10-12]. The stability of the grains in the drying bed causes the rice paddies in the lower parts to be more in contact with the incoming air and, compared to the rice pads located in the upper layers, to balance with the surrounding air conditions sooner.They are ripe and dry.Since rice is a hygroscopic grain and is easily affected by environmental conditions [14-13], it can be expected that grains with less moisture will absorb moisture from the grains with more moisture, as well as the surrounding environment, and cracks will occur in the grain [15]. The formation of cracks due to the absorption of moisture and the creation of moisture stress in the grain after the drying operation and subsequent breakage during the conversion operation is the main reason for the reduction of the efficiency of healthy rice in the conversion industry [16]. To overcome the difference in humidity and temperature created in this type of fixed bed dryer, there are two ways, which can be referred to the movement of paddy inside the dryer or changing the air flow. Since in these dryers, the possibility of paddy movement in the dryer is very low, so changing the direction of the air flow is a practical solution that can be used. The results of Ibrahim et al.'s (2013) and Tadjadi Talab's (2012) researches showed that changing the direction of air flow in fixed bed dryers has a significant effect on reducing energy consumption, increasing drying capacity, and producing healthy rice. Tadjadi Talab (2012) stated that due to the significant reduction of healthy rice production, it is not recommended to increase the height of the drying box bed to more than 50 cm.

Improving quality based on consumer preferences, along with attention to waste reduction, is a category that is always considered by the rice industry. Rice is one of the grains that undergo changes during storage after harvesting[1] It is said [19]. These changes are often favorable for rice consumers [20], including Iranian consumers. Expedited processing[2] It is a process that in a short period of time creates a desirable quality similar to old rice in fresh ricehe does[21]. Steaming is one of the accelerated treatment methods and the shortened method of semi-boiling process[3] in which the soaking step is removed [22], the results of studies in which steaming treatment was used before the drying operation, show the positive effect of steaming operation on the quality of rice, especially healthy rice and its cooking characteristics [19, 21- 24 [. Because during the steaming process, the moisture content of paddy increases, so to prevent the growth of microorganisms (mushrooms, yeasts and bacteria) and change the color of rice, it is necessary to dry this type of paddy in the shortest possible time.Action. Promotion of steaming method, especially in small scale (farmers), requires introduction of suitable and cheap dryer.Although the non-movement of paddy in the bed of conventional box dryers is considered the main factor of non-uniform drying, but by modifying them through the use of practical methods such as changing the air flow, it can be expected that in addition to reducing waste, energy consumption can also be saved. Although the results of the research show the positive effects of changing the air flow method

[1]. Aging

[2]. Accelerated Aging

[3]. Parboiling

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on improving the quality of the final product and drying performance, but an important factor such as the early change of air flow can be the problem of moisture absorption and cracking of rice with lower moisture in the opposite layers, and the subsequent increase in waste in the form of broken rice. from the conversion operation. The main purpose of this research is the possibility of using the reverse air flow method for drying steamed paddy and its effect on the quality properties of rice, energy consumption and performance of the fixed bed box dryer and providing a suitable drying method.

2- Materials and methods

2-1- Test method

2-1-1-Evaporation

In this research, according to the favorable results of previous researches, Hashemi variety rice steaming treatment was used for 5 minutes before drying operation [21,25]. In this study, the initial moisture level of Badu rice was 18.5 ± 1% 16 ± 0.5 was used based on fresh weight. Freshly harvested wet paddy was first dried in the field before threshing. The paddy obtained from threshing had an approximate moisture content of 16% (based on wet weight). Before the steaming operation, in order to bring the moisture content of rice paddies to 18%, it was necessary to add water to them, which was calculated using the following formula: [26]:

$$\text{Volume of water (liters)/grain (ton)} = \frac{M_1 - M_2}{100 - M_2} \quad (1)$$

M_1 and M_2They are the amount of seed moisture (%) after and before moistening, respectively.

The samples were steamed without soaking for 5±1 minutes using a laboratory parboil (semi-boiling) device with a capacity of 7 kg. The device is cylindrical in shape and includes two upper and lower parts. Waterwith the helpAn electric element boils in the lower part of the device and the resulting vapors under atmospheric pressure with a temperature of 100 degrees Celsius are transferred to the rice paddy through the mesh bottom and hollow tubes installed in the upper part of the device.It will be given.The vaporized samples were dried after resting for 18 hours.

2-1-2- drying

To carry out the drying operation, a common horizontal non-continuous dryer, conventional one-way air flow (from bottom to top) in the rice milling industry and reverse air flow were used. In this method, the air flow was first established from top to bottom, and at three different times, 1, 2, and 3 hours after the drying operation, the direction of air flow was changed and continued from bottom to top; Therefore, four treatments were used for drying. The drying temperature and depth of the bed were fixed for all treatments and were considered 45°C and 40 cm, respectively. The final humidity was 9±0.5% (w.b). For the drying operation, a dryer that was designed and built on a laboratory scale with two air inlets, from the bottom and the top, was used.became.

During the drying process, sampling was done at half-hour intervals from different upper, middle, and lower layers at depths of 30, 20, and 10 cm from the floor of the dryer (respectively) through valves installed on the wall of the dryer at these intervals. The drying process continued until the desired moisture content was reached in each drying method. The criterion for the end of the process was to control the moisture content of the paddy in the upper layer. At the end of the drying process, samples were collected from the upper, middle and lower parts of the dryer. In addition, a sample was also prepared from the combination of different drying layers. Ambient air conditions (dry bulb temperature and relative humidity) were recorded using a data logger. The wet and dry bubble temperature and the temperature of hot air entering the dryer were recorded using a hygrothermometer. The temperature in different parts of the dryer was recorded by a data logger (Pico technology, model TC-08, UK). Paddy moisture was measured with a GMK303 G-Won digital moisture meter made in Korea.

2-2- Evaluation of energy consumption

Consumed energy includes two parts: thermal energy to heat the air and electrical energy to move the blower fan. The following equations were used to calculate the energy consumption of paddy drying [2]. The efficiency of the power generation device for converting thermal energy into electrical energy is considered to be 38.5%; Therefore, the conversion factor is 2.6 = 100/38, which is used in the equation to convert electrical energy into primary energy.

(2) $$E_{elec}=2.6P\times t$$

(3) $$E_{heat}=m_a c_a (T_{mix}-T_i)$$

(4) $$m_a=Q\times \rho_a \times t$$

(5) $$Q=A\times V$$

The total moisture evaporated from paddy in each batch was calculated using mass balance equations [2]. Dryer performance and total energy consumption were finally calculated through the sum of electrical and thermal energy in megajoules per kilogram of water (MJ/kg) evaporated.

(6) $$F=P+W$$

(7) $$F.X_f=P.X_p$$

In the above equations, Q is the air flow rate entering the dryer chamber (m^3s^{-1}), A cross-sectional area of the incoming flow (m^2), V average speed of drying air in the inlet section (ms^{-1}), AND$_{he}$Electric energy consumed by dryer blower fan (KJ), E_{heat} Thermal energy used to heat the drying air (kJ), P blower motor power (kw), t total drying time (h), m_a Mass of drying air (kg),$_a\rho$ air density (kgm^{-3})، C_a Specific heat of drying air ($kjkg^{-1o}C^{-1}$)، T_i Ambient air temperature (^OC)، T_{mix} drying air temperature (^OC), F is the weight of rice with initial moisture (kg), P is the weight of dried rice with final moisture (kg), w is the amount of moisture removed (kg), X_p , X_f The solid component of primary paddy and dried paddy, respectively.

2-3- Measurement of drying capacity

In order to measure the drying capacity, the following equation was used [27]:

$$\text{drying capacity} = \frac{\text{Wet paddy weight (ton/m2)}}{\text{Total drying time (h)}}$$

2-4- Measuring the drying rate

The following equation was used to measure the drying rate [28]:

(9) $$(\%h^{-1})\ \text{drying rate}=\frac{\text{IMC-FMC}}{t}$$

IMC initial moisture content (%w.b), FMC final moisture content (%w.b), t total drying time.

5-2- Efficiency of healthy rice

150 grams of dried paddy was separated using Satake's laboratory rubber roller peeler. McGill No. 2 laboratory bleach was used for bleaching. Then, the healthy white rice was separated from the broken rice with an indent laboratory rotary sieve made by Satake Co., Japan. Healthy rice is rice whose length is at least three quarters of the length of a whole white rice grain [29]. The percentage of healthy rice was calculated using equation 10.

(10) $$\text{HRY}(\%)=\frac{\text{HR(gr)}}{\text{WR(gr)}}\times 100$$

HR: healthy rice weight and WR: white rice weight.

6-2- Cooking characteristics

Baking characteristics were investigated according to the method of Singh and his colleagues (2005).

Minimum cooking time: 2 grams of healthy rice samples that had been soaked for half an hour were poured into a test tube, then 20 ml of distilled water was added and placed in a hot water bath. After a few minutes, rice grains were alternately removed and pressed between two glass plates, this work continued until no white spots were observed.

Percentage of solids lost: The cooked rice water was transferred to the dry Erlenmeyer which was weighed in advance and then placed in the oven at 105 degrees Celsius until completely dry. The difference in the weight of Erlen before and after drying is the amount of solids lost, which was reported as a percentage.

Elongation ratio: The ratio of the length of 10 cooked seeds to the length of 10 raw seeds.

Water absorption ratio: The ratio of the weight of 10 cooked seeds to the weight of 10 raw seeds.

2-7- Determination of color

Color measurement was done using Hunter Lab (color flex, model 0.45, USA). After calibration using black and white tiles, the color values were expressed using L* (lightness), a* (red-green) and b* (yellow-blue) parameters [31].

8-2- Statistical analysis

A two-factor experiment in the form of a

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completely randomized design was used to perform statistical tests with the help of Minitab software (ver16). Factors including initial humidity at two levels (16 and 18%) and air flow direction at 4 levels (one-way air flow, reverse air flow for 1 hour, 2 hours and 3 hours from above) were considered. The comparison of means was done by Tukey's method at the probability level of 5%. Tests were performed in three repetitions and Origin (2019b) software was used to draw graphs.

3. Results and Discussion

1-3-Chart of paddy drying in different layers of dryer

As seen in figures 1 to 4, in a short period of time, the rate of moisture exit from the grain is very slow, which is due to evaporative cooling.[4]It is related at the beginning of the drying operation. According to Kumar et al. (2015), at the beginning of the drying process, because the surface of the grain is almost saturated in terms of moisture, the high rate of evaporation and removal of moisture leads to a drop in temperature and a decrease in the process of moisture exiting the paddy [33,34]. The effect of cooling is related to the drying air temperature, grain moisture content and air flow speed [18].

With the continuation of the drying operation, depending on whether the layers are far or close to the incoming air, with the decrease of humidity and the increase of temperature in the layers, the rate of exit of humidity increased and with the passage of time the process of decreasing humidity slowed down (Figures 1 to 4). Other researchers also reported similar results [2,5,35,36]. In general, in the first hours of the drying operation, the moisture on the grain surface can be easily removed by hot air [37, 36]. After that, the moisture in the central parts of the seed slowly diffuses to the surface of the seed, and this diffusion of moisture limits the drying speed [36] and slows down the removal of moisture. In the final stages, depending on the drying method, humidity and temperature conditions inside the dryer, the humidity of different layers approached each other in different periods of time (Figures 1 to 4). down), after changing the direction of the air flow (blowing air from the bottom to the top) in the interval of 180 to 210 minutes, due to the absorption of moisture, no significant change in the moisture content of the rice paddies located in the above layers was observed.

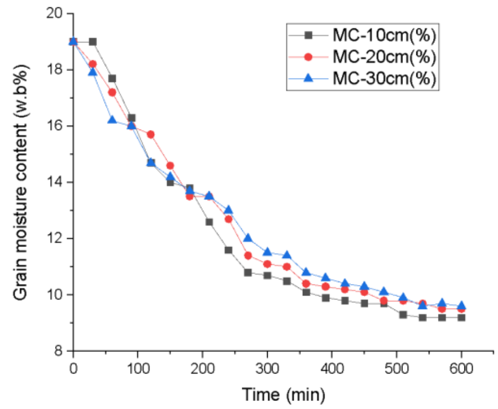

Fig 1 Paddy drying curve at different layers for reverse air flow drying of one hour from top

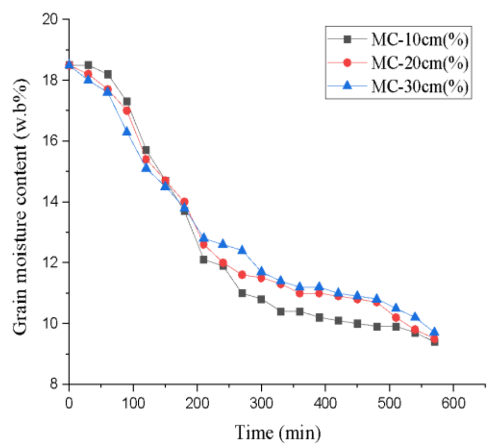

Fig 2 Paddy drying curve at different layers for reverse air flow drying of two hours from top

As can be seen in Figure 3, in terms of the moisture reduction process in the final stages, the drying method with reverse air flow for 3 hours was the most uniform, so that after about 4 hours

4. evaporative cooling

have passed since the beginning of the drying process, the moisture content of the different layers is very close to each other. became This is a sign that the temperature in different layers of paddy is closer in this drying method compared to the one-way flow method, which can be seen in Figures 5 and 6. As can be seen in figures 3 and 4, before 3 hours have passed, the process of moisture change in the layers is almost similar to the one-way flow drying method. Sufficient removal of moisture from the rice paddies located in the upper layers due to the change in air flow after a longer period of time leads to the relative humidity of the air around the grains at the time of air return reaching a condition where the drying process can proceed more uniformly and in the shortest time using the method One-way flow is terminated (figures 3 and 4).

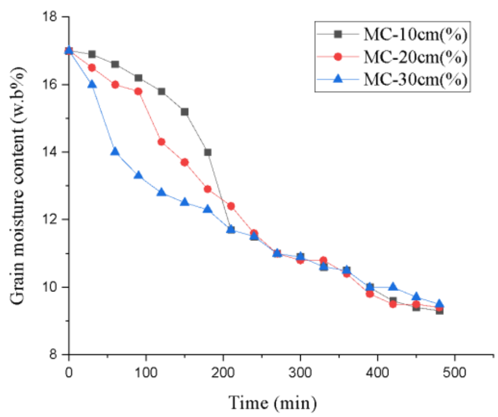

Fig 3 Paddy drying curve at different layers for reverse air flow drying of three hours from top

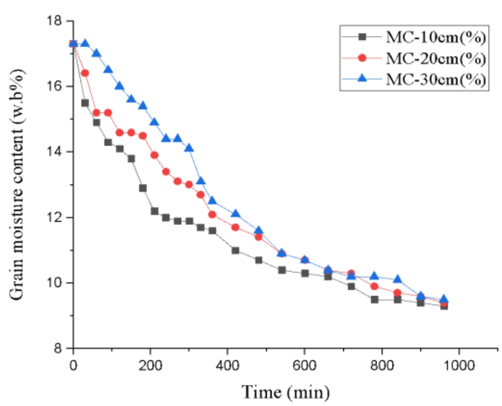

Fig 4 Paddy drying curve at different layers for single direction air flow drying

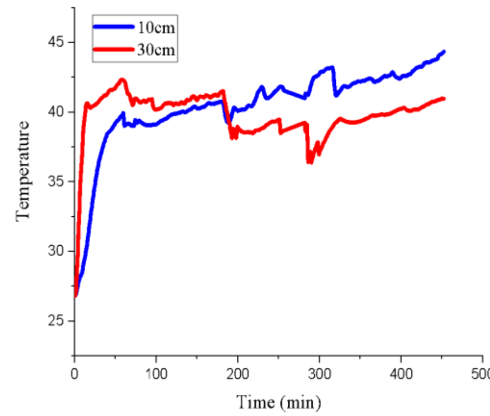

Fig 5 Temperature profile inside dryer for reverse air flow drying three hours from top

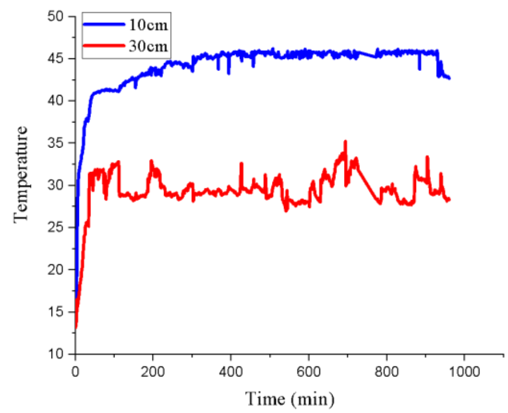

Fig 6 Temperature profile inside dryer for single direction air flow drying

As can be seen in Figure 6, since in the one-way flow drying method, the temperature difference between the layers was relatively large from the beginning to the end of the drying process, so the rice paddies located in the upper layers needed more time to reach the final moisture content of 0.9 ± 0.5%. so that the air conditions around them, especially in terms of relative humidity, reach the appropriate stage in terms of equilibrium humidity. Also, by changing the air flow after three hours and reducing the air temperature by about 5 degrees in the 30 cm layer, an opportunity was created for the moisture in the central parts of the grain to be slowly directed towards the outer layers and to be able to leave the grain easily without moisture and thermal stress. .

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3-3- Evaluation of drying time, energy consumption, drying rate and capacity

As can be seen in Table 1, in both humidity levels, by using the method of changing the direction of the air flow after three hours, the drying time has been shortened, the energy consumption has been reduced and the drying capacity has been increased. The longest drying time is related to one-way flow treatment, which results in maximum energy consumption and minimum drying capacity in this treatment. The highest average drying rate was observed in the two-way air flow treatment 3 hours from above and the lowest drying rate was observed in the one-way air flow treatment. Among the other two methods of reverse air flow (1 hour and 2 hours), the 2 hour treatment had better conditions in terms of energy consumption, drying time, capacity and drying rate. The results of the research by Ibrahim and his colleagues (2013) and Taddaditab (2012) also show the positive effect of reverse air flow on increasing the drying capacity, reducing the drying time and energy consumption in the variety.shows.

Table 1 Drying Time, Total Energy, Drying capacity, and Average Drying rate for different drying methods

Average Drying rate (%h^{-1})	Drying Capacity (Ton/m^2h)	Total Energy (MJ/kg water)	Drying Time (h)	Drying method
0.49	0.012	79	16	hS
0.95	0.018	62	10	hR-1h
0.94	0.019	60	9.5	hR-2h
0.95	0.023	49	8	hR-3h
0.63	0.016	67	11	lS
0.75	0.020	48	8.3	lR-1h
0.76	0.022	46	8	lR-2h
0.98	0.023	41	7.5	lR-3h

h=high moisture, l=low moisture, S=single direction air flow drying, R-1h=reverse air flow drying-1 hour from top, R-2h=reverse air flow drying-2 hour from top, R-3h=reverse air flow drying-3 hour from top

3-4- Efficiency of healthy rice

The results of this research show that in both humidity treatments (high and low), in all three layers, the highest efficiency of healthy rice was related to the 3-hour reverse air flow treatment, and the results of this treatment were for the one- and two-hour reverse air flow and one-way air flow treatments. , there was a significant difference at the 5% level. One-hour reverse air flow treatment had the lowest amount of healthy rice in the layers and the combined sample obtained from three layers. According to the results of the mixture of layers, in both humidity treatments, the two-hour reverse flow treatment had the lowest value after the one-hour reverse air flow treatment (Table 2). The observed reduction of healthy rice in layers and mixed samples in two one-hour and two-hour reverse air flow treatments in many cases, even compared to one-way flow, can be attributed to two important factors, including the high rate of paddy drying in the layers and the cracking of the paddy in the upper layers. The reason for moisture absorption should be related immediately after changing the direction of air flow. Although the results of Table 1 show that the average drying rate is outside the critical value of h^{-1}The 1.5% announced by Ban (1971) quoted by Champagni (2004) is not, but the examination of the data recorded at different hours shows that the drying rate is high compared to the critical limit, especially in some layers. In the reverse flow treatment of two and one hour, in the 30 cm and 10 cm layer for a long period of 5 to 5.30 hours, they experienced a drying rate higher than 1.5. Meanwhile, in the three-hour reverse flow drying method, the 30 cm layer, which had a drying rate higher than 1.5 for the first three hours, became less than the critical level when the air flow was reversed. Increasing the drying rate in the 30 cm layer did not reduce healthy rice (Table 2). In the early hours of the drying process, the rice has more moisture because moisture escapes from its surface areas, so in this case, the possibility of cracking due to thermal and moisture stress and subsequently reducing the amount of healthy rice is low. In addition, the change in air flow after 3 hours of drying operation and the decrease in temperature in the upper layers created an opportunity to slowly direct the moisture from the internal parts to the external parts of the seed without causing moisture and thermal stress. In this way, the efficiency of healthy rice in the centimeter layer was higher than other treatments. It should be said that the 10 cm layer in the 3-hour reverse flow treatment and the 30 cm layer in the one-way flow from the beginning to the end of the drying process had a drying rate below the critical limit. Another factor that could be effective in reducing the percentage of healthy rice produced is the absorption of moisture after the return of the air flow in one or two hours. In the one-way flow treatment, the lowest amount of healthy rice observed in the 10 cm layer can be related to the continuous drying of this layer until the rice moisture in the upper layers reaches the appropriate level. In the 3-hour reverse flow treatment, the reduction of humidity in the lower layers at the time of air flow change is an effective factor in reducing the possibility of moisture absorption and subsequent cracking and reduction of healthy rice in the upper layers, and in terms of healthy rice produced in both initial humidity levels, the highest amount (Table 2). In fact, after the return of the air flow and the rice paddies located in the lower layers facing warmer air, their moisture content was enough to not damage the low moisture paddies located in the upper layers.

Table 2 HRY for different drying methods

GAMES (mixed grains of dryer layer) (%)	GAMES (bottom layer) (%)	GAMES (middle layer) (%)	GAMES (top layer) (%)	Drying method
72.34±0.68[abc]	63.65±1.93[c]	71.75±0.96[c]	72.61±0.52[ab]	**hS**
65.88±2.21[It is]	65.47±2.89[bc]	68.47±1.47[c]	67.26±0.41[c]	**hR-1h**
68.28±1.68[of]	69.84±1.71[abc]	69.68±0.76[c]	69.76±1.19[bc]	**hR-2h**
75.86±0.61[a]	74.98±0.83[a]	76.07±1.44[a]	76.28±0.36[a]	**hR-3h**
72.16±1.83[bc]	67.66±5.17[bc]	72.03±2.05[bc]	68.54±3.04[c]	**lS**
68.86±0.08[cde]	69.27±0.23[abc]	68.91±0.82[c]	68.18±0.16[c]	**lR-1h**
71.21±0.37[cd]	71.19±1.12[ab]	71.92±1.15[c]	70.28±0.54[bc]	**lR-2h**
75.7±0.64[ab]	75.11±0.75[a]	75.73±0.46[ab]	74.76±1.58[a]	**lR-3h**

h=high moisture, l=low moisture, S=single direction air flow drying, R-1h=reverse air flow drying-1 hour from top, R-2h=reverse air flow drying-2 hour from top, R-3h=reverse air flow drying-3 hour from top
Mean values ± standard error mean (SEM), the same lower case letters are not significantly different (P >0.05)

In this method, the amount of moisture in the layers of 30, 20 and 10 cm is 12.3, 12.9 and 14%, respectively, and for the two-hour reverse flow, it is 1.15, 15.4 and 15.7, respectively, and the one-hour reverse flow method is 2.2, respectively. 16, 2/17 and 7/17.According to the results of this research, 15-16% can be considered as the critical moisture range for Hashemi rice. Juliano and Perez (1993) declared the critical humidity for the sensitive variety IR42 to be 16% and for the variety IR60 in dry and wet seasons, 14 and 12%, respectively. What is very important in the return air flow method is to prevent and significantly reduce moisture reabsorption by the upper layers after changing the air flow, so it is necessary to change the air flow when the lower layers have less moisture.

5-3- Cooking and color characteristics

The results of Table 3 show that different drying methods at the 5% level did not have a significant effect on the cooking characteristics, including minimum cooking time, lost solids, elongation ratio and water absorption ratio. Due to the non-significance of all the results, only the information related to the mixed samples of different layers has been given. Also, different drying methods had no significant effect on color parameters such as L*, a*, b* (Table 3). Since in this research, the important factors of drying, including the height of the bed, the final moisture of the paddy, and the temperature of the dryer were the same in all treatments, therefore, the lack of difference observed in the results of the cooking characteristics and the color of the final product is not far from expected.

Table 3 Cooking properties and color of rice for different drying methods

b*	a*	L*	Elongation ratio	Water uptake	Solid loss (%)	Cooking Time (min)	Drying method

				ratio			
19.19±0.35^{a}	1.37±0.02^{a}	67.36±0.93^{a}	1.64±0.02^{a}	2.74±0.21^{a}	23.43±2.2^{a}	13.33±0.57^{a}	**hS**
18.93±0.44^{a}	1.38±0.18^{a}	69.08±0.66^{a}	1.65±0.08^{a}	2.47±0.14^{a}	23.7±1.05^{a}	13±0^{a}	**hR-1h**
18.3±0.18^{a}	1.52±0.24^{a}	68.64±0.71^{a}	1.65±0.08^{a}	2.58±0.33^{a}	22.8±0.2^{a}	13±0^{a}	**hR-2h**
19.16±0.44^{a}	1.51±0.12^{a}	68.41±1.06^{a}	1.66±0.05^{a}	2.81±0.34^{a}	22.06±3.18^{a}	13±0^{a}	**hR-3h**
18.97±0.11^{a}	1.34±0.11^{a}	67.48±0.46^{a}	1.64±0.03^{a}	3±0.12^{a}	22.83±4.21^{a}	12.66±0.57^{a}	**lS**
19.17±0.54^{a}	1.37±0.18^{a}	68.49±0.51^{a}	1.66±0.9^{a}	2.8±0.08^{a}	23.83±4.4^{a}	13±1^{a}	**lR-1h**
19.24±0.11^{a}	1.61±0.25^{a}	68.18±0.55^{a}	1.63±0.03^{a}	2.74±0.09^{a}	23.26±1.29^{a}	13.33±0.57^{a}	**lR-2h**
18.95±0.48^{a}	1.42±0.37^{a}	68.41±0.7^{a}	1.67±0.02^{a}	2.66±0.14^{a}	22.33±3.13^{a}	13±0^{a}	**lR-3h**

h=high moisture, l=low moisture, S=single direction air flow drying, R-1h=reverse air flow drying-1 hour from top, R-2h=reverse air flow drying-2 hour from top, R-3h=reverse air flow drying-3 hour from top

Mean values ± standard error mean (SEM), the same lower case letters are not significantly different ($P > 0.05$)

4 - Conclusion

According to the results of this research, the longest drying time was related to one-way flow treatment, which resulted in maximum energy consumption and minimum drying capacity compared to other samples in each moisture treatment. The three-hour reverse flow drying treatment had the minimum value in this regard. In both humidity treatments (high and low), in all three layers, the highest efficiency of healthy rice was related to the three-hour reverse air flow treatment. The early change of air flow in the reverse flow drying operation of paddy, especially in paddy with high initial moisture, led to a decrease in healthy rice produced in the layers and the combined sample obtained from three layers compared to the one-way flow drying method. Although the use of a box dryer equipped with reverse air flow instead of one-way flow can play an effective role in preventing excessive drying of the lower paddies, but the incorrect selection of drying parameters in this type of dryer can cause moisture absorption by the dried paddies in the mutual layers and finally lead to an increase in waste in the form of broken rice; Therefore, it is necessary to manage the change of air flow in such a way that moisture absorption in the cross layers is minimized.

6- Resources

[1] Gazor, H. R., and Alizadeh, M. R. (2020). Comparison of rotary dryer with conventional fixed bed dryer for paddy drying, milling quality and energy consumption. Agricultural Engineering International: *CIGR Journal*, *22*(2), 264-271.

[2] Sarker, M. S. H., Ibrahim, M. N., Aziz, N. A., and Salleh, P. M. (2014). Energy and rice quality aspects during drying of freshly harvested paddy with industrial inclined bed dryer. *Energy conversion and management*.77, 389-395.

[3] Prachayawarakon, S., Sawanduianpen, S., Saynampheung, S., Poolp- atarachewin, T., Soponronnarit, S., and Nathakarakule, A. (2004). Kinetics of colour change during storage of dried garlic slices as affected by relative humidity and temperature. *Journal of Food Engineering*. 62: 1–7.

[4] Jittanit, W., Saeteaw, N. and Charoenchaisri, A. (2010). Industrial paddy drying & energy saving options. *Journal of Stored Products Research*. 46(4): 209-213.

[5] Sarker, M. S. H., Ibrahim, M. N., Aziz, N. A., andPunan, M. S. (2015). Overall energy requisite and quality feature of industrial paddy drying. *Drying Technology*.*33*(11), 1360-1368.

[6] Ogura, H., Hamaguchi, N., Kage, H., and Mujumdar, A. S.(2004). Energy and Cost Estimation for Application of Chemical Heat Pump Dryer to Industrial Ceramics Drying. *Dry Technol*. 22: 307–323.

[7] Mondal, M. H. T., Shiplu, K. S. P., Sen, K. P., Roy, J., andSarker, M. S. H. (2019). Performance evaluation of small scale energy

efficient mixed flow dryer for drying of high moisture paddy. *Drying Technology*.*37*(12): 1541-1550.

[8] Goyal, S. K.,Jogdand, S. V., Agrawal, A. K. (2014). Energy Use Pattern in Rice Milling Industries-a Critical Appraisal. *J. Food Sci. Technol*. 51: 2907–2916.

[9] Ghiasi, M., Ibrahim, M. N., Kadir Basha, R., and Abdul Talib, R. (2016). Energy usage and drying capacity of flat-bed and inclined-bed dryers for rough rice drying. *International Food Research Journal*, 23:S23-S29.

[10] Souza, G. F. M. V., Miranda, R. F., Lobato, F. S., and Barrozo, M. A. S. (2015). Simultaneous heat and mass transfer in a fixed bed dryer. *Applied Thermal Engineering*. *90*: 38-44.

[11] Bennamoun, L., and Belhamri, A. (2008). Mathematical description of heat and mass transfer during deep bed drying: Effect of product shrinkage on bed porosity. *Applied Thermal Engineering*. *28*(17-18), 2236-2244.

[12] Ling, G., and Jianping, W. (2001). Study on the moisture uniformity of paddy drying technology by employing air direction reversals. *J. Zhejiang Univ*. 27 (5): 587–590.

[13] Champagne, E. T. (2004). Rice: Chemistry and Technology. 3rd ed. St. Paul, Minn.: American Association of Cereal Chemists.

[14] Chakraverty, A., and P. Singh. (2001). Postharvest Technology: Cereals, Pulses, Fruits, and Vegetables. Enfield, N.H.: Science Publishers.

[15] Kunze, O. R., and Prasad, S. (1978). Grain fissuring potentials in harvesting and drying of rice. *Across. ASAE*. 21(2): 361-366.

[16] Lan, Y., and O. R. Kunze. (1996). Fissure resistance characteristics related to moisture adsorption stresses in rice. *Across. ASAE*. 39(6): 2169-2174.

[17] Ibrahim, M. N., Talab, K. T., Spotar, S., Muhammad, K., and Talib, R. A. (2013). Effects of airflow reversal in fixed-bed drying of rough rice on head rice yield and drying performance. *Transactions of the ASABE*. *56*(4): 1485-1493.

[18] Tajaddodi, K. (2012). Fixed-bed drying of rice with airflow reversal for product quality and drying performance. Serdang, Malaysia: Universiti Putra Malaysia, PhD thesis.

[19] Latifi, A., and Esmaiili, M. (2019). Effect of Steam Curing of Shiroudi Paddy on Quality, Texture and Thermal Properties of Rice.*Food Engineering Research*. 67: 61-72

[20] Zhou, Z., Robards, K., Helliwell, S., Blanchard, C. (2002). Ageing of stored rice: Changes inchemical and physical attributes. *Cereal Science*. 35(1): 65-78.

[21] Tajaddodi Talab, K. Effect of commercial Guilan and Mazandaran rice varieties steaming onmilling quality, physicochemical characteristics and nutritional value ofrice and pests during storage. (2020). Final report of project.*Rice Research Institute of Iran*. Page 87

[22] Tajaddodi- Talab, K., Alipanah, F., Shahidi, A. (2020). Effect of steaming on bending strength and milling quality of high yield rice variety. *Food Engineering Research*. 69: 43-56

[23] Latifi, A., andEsmaiili, M. (2017). Effect of accelerated aging on physicochemical properties of rice cultivar Tarom. *Iranian Food Science and Technology Research Journal*.*13*(5), 798-807

[24] Gujral, H.S., and Kumar, R. (2003). Effect of accelerated aging on the physicochemical and textural properties of brown and milled rice. *Journal of Food Engineering*. 59(2-3), 117-121

[25] Hasannia, F., Tajaddodi Talab, K., Shahidi, S. A., and Ghorbani-Hasansaraei, A. (2022). Effect of steam curing on pasting and textural properties, starch structure and the quality of a local aromatic rice variety. *Journal of food processing and preservation*. 46(10), e16857.

[26] Mclean. K. A. (1989). Drying and storing combinable crops. 2nd Edition. Farming Press. United Kingdom.256p.

[27] Islam, M. T., B. P. Marks, and F. W. Bakker-Arkema. (2004). Optimization of commercial ear-corn dryers. Agric. Eng. Intl.: *CIGR Ejournal*6: Manuscript FP04007.

[28] Ban, T. (1971). Rice cracking in high-rate drying. *Japanese Agric. Res. Qtly*. 6: 113-116.

[29] Thakur, A. K. and Gupta, A. K. (2006). Two stage drying of high moisture paddy with intervening rest period. *Energy Conversion and Management*. 47(18-19): 3069-3083.

[30] Singh, N., Kaur, L., Sohdi, N.S., and Sekhon, K.S.(2005). Physicochemical, cooking and textural properties of milled rice from different Indian rice cultivar. *J. Food Chem*. 89: 253-259.

[31] Good, H. (2002). Measurement of color in

cereal products. *Cereal FoodsWorld*.4: 5–6.

[32] Kumar, C., Millar, G.J., and Karim, M. A.(2015). Effective diffusivity and evaporative cooling in convective drying of food material. *Drying Technology*. 33: 227–237.

[33] Zhang, W., Mujumdar, A.S. (1992). Deformation and stress analysis of porous capillary bodies during intermittent volumetric thermal drying. *Drying Technology*. 10(2): 421–443.

[34]Turner, I.W., Jolly, P.C. (1991). Combined microwave and convective drying of a porous material. *Drying Technology*. 9 (5), 1209–1269.

[35] Kumoro, A. C., Lukiwati, D. R., Praseptiangga, D., Djaeni, M., Ratnawati, R., Hidayat, J. P., and Utari, F. D. (2019, November). Effect of Bed Thickness on the Drying Rate of Paddy Rice in an Up-flow Fixed Bed Dryer. In *Journal of Physics: Conference Series* (Vol. 1376, No. 1, p. 012045). IOP Publishing

[36] Rao P.S., Bal S., and Goswami T.K. (2007). Modelling and Optimization of Drying Variables in Thin Layer Drying Of Parboiled Paddy.*J. Food Eng*. 78: 480–487.

[37] Gunathilake, D. M. C. C.,Senanayaka, D.P.,Adiletta, G. and Senadeera, W. (2018). Drying of agricultural crops. In book: Advances in Agricultural Machinery and Technologies 1th Edi. Taylor and Francis Group. CRC Press. Pp: 331-365.

[38] Champagne, E. T. (2004). Rice: Chemistry and Technology. 3rd ed. St. Paul, Minn.: American Association of Cereal Chemists.

[39] Juliano, B., Perez, C. M. (1993). Critical moisture content for fissures in rough rice. *Cereal Chem*.70: 613-615.

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فرزانه حسن‌نیا[۱]، کبری تجددی طلب [۲*]، سید احمد شهیدی[۳]، آزاده قربانی حسن‌سرایی[۳]

۱- دانشجوی دکتری، گروه علوم و صنایع غذایی، واحد آیت ا... آملی، دانشگاه آزاد اسلامی، آمل، ایران.

۲- استادیار مهندسی صنایع غذایی، موسسه تحقیقات برنج کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی، رشت، ایران.

۳- دانشیار گروه علوم و صنایع غذایی، واحد آیت ا... آملی، دانشگاه آزاد اسلامی، آمل، ایران.

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* مسئول مکاتبات:

dr2eng@yahoo.com

چکیده

خشک‌شدن غیر یکنواخت و کاهش برنج سالم تولیدی به دلیل عدم جابجایی شلتوک در خشک‌کن‌های بستر ثابت متداول یکی از مشکلات اساسی در کارخانه‌های برنج‌کوبی است. به‌منظور بررسی و ارائه روش خشک‌کردن مناسب با رویکرد ایجاد یکنواختی در عملیات خشک‌کردن، کاهش ضایعات، صرفه‌جویی مصرف انرژی مصرفی در خشک‌کن‌های بستر ثابت متداول از آزمایش دو فاکتوره در قالب طرح کاملاً تصادفی استفاده شد. فاکتورها شامل رطوبت اولیه شلتوک در دو سطح (۱۶ و ۱۸ درصد) و روش خشک‌کردن در ٤ سطح (جریان هوای یک‌طرفه، جریان هوای معکوس به مدت ۱ ساعت، ۲ ساعت و ۳ ساعت، سپس برگشت هوا و ادامه عملیات خشک‌کردن همانند جریان یک‌طرفه) بودند. دما و سرعت جریان هوای خشک‌کن برای کلیه تیمارها یکسان در نظر گرفته شد. در هر دو تیمار رطوبتی، خشک‌کردن به روش جریان معکوس به مدت سه ساعت، بیشترین مقدار برنج سالم (۷۵/۸٦-۷۵/۷ درصد) و کمترین مقدار انرژی مصرفی (٤۹-٤۱ مگاژول بر کیلوگرم آب) را به خود اختصاص دهد. بیشترین انرژی مصرفی با مقادیر ۷۹ و ٦۷ مگاژول بر کیلوگرم آب به ترتیب متعلق به تیمار جریان هوای یک‌طرفه شلتوک با رطوبت اولیه بالا و پائین (به‌ترتیب) بود. در روش خشک‌کردن جریان یک‌طرفه، شلتوک‌های خشک‌شده در لایه ۱۰ سانتی‌متری از کف خشک‌کن، کمترین مقدار برنج سالم (٦۳/٦٥ درصد) را داشتند. در هر دو تیمار رطوبتی، نتایج مخلوط لایه‌ها نشان داد خشک‌کردن جریان معکوس یک‌ساعته با مقادیر ٦۸/٦۸-٦۸/۲۸ درصد دارای کمترین مقدار برنج سالم بودند. هم‌چنین‌روش خشک‌کردن اثر قابل‌ملاحظه‌ای($P > 0.05$) بر کیفیت پخت نداشت.